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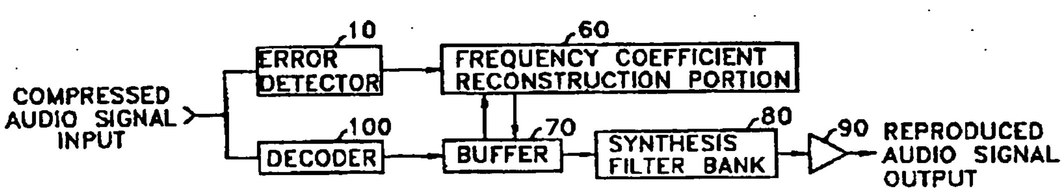
(54) **Error concealment method and apparatus of audio signals**

(57) An apparatus for concealing a frame or multiple of frames where errors have occurred in a digital audio signal which is subband coded and transform coded in units of an error-correctible frame is described. The error concealment apparatus includes an error detector (10) for receiving frequency coefficients representing the encoded digital audio signal and detecting whether an error has occurred for each frame, a decoder (100) for decoding the frequency coefficients by respective subbands forming a frequency domain of the whole audio signal with respect to the input frequency coefficients, a buffer (70) for storing the frequency coefficients decoded by said decoder (100), a frequency coefficient reconstruction portion (60) for reconstructing the frequency coefficients of a frame or multiple of frames where errors have occurred using predetermined weight values and frequency coefficient(s) of subband adjacent to the error frame(s) among the frequency coefficients belonging to a frame which is stored in the buffer (70) and is adjacent to the error frame(s), and updating the frequency coefficients of the error frame(s), and storing the frequency coefficients in the buffer (70), in response to the error detection result from error detector (10) and a synthesis filter bank (80) for receiving the frequency coefficients stored in the buffer (70) and converting the frequency coefficients into an audio signal of a time domain, in the same sequence as a decoding sequence.

FIG. 5



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(f) updating the frequency coefficients of the error frame(s) stored in step (d) with the frequency coefficients reconstructed in step (e); and

(g) converting the frequency coefficients resulting from step (f) into an audio signal of a time domain, in the same sequence as that decoding in step (c).

Said step (e) may use frequency coefficients subbands which exist in the very previous frame of the error-generated frame(s) and is adjacent to the error-generated frame(s), to reconstruct the frequency coefficients of subbands of the error-generated frame(s). Said frequency coefficients may belong to the last segment of frame which is immediately preceding the error-generated frame(s). Said step (e) may calculate frequency coefficients corresponding to subbands of the error-generated frame(s), by multiplying the frequency coefficient adjacent to the error-generated frame(s) which belongs to the very previous frame for each subband, by a predetermined weight value. Said predetermined weight values may be less than or equal to one.

Alternatively, said step (e) may use frequency coefficients for subband(s) which exist in the very previous frame and the very succeeding frame of the error-generated frame(s) and is adjacent to the error-generated frame(s), to reconstruct the frequency coefficients for each subband of the error-generated frame(s). Said frequency coefficients may respectively belong to the last segment of the frame which is immediately preceding the error-generated frame(s) and the first segment of the frame succeeding the error-generated frame(s). Said step (e) may calculate frequency coefficients corresponding to subbands of the error-generated frame(s), by multiplying the frequency coefficient adjacent to the error-generated frame(s) which belongs to the very previous frame for each subband, by a first weight value, multiplying the frequency coefficient adjacent to the error-generated frame(s) which belongs to the very succeeding frame for each subband, by a second weight value, and adding the two multiplication results. Said first and second weight values may be less than or equal to one.

Preferably, said step (e) replaces said predetermined weight values for the audio muting by a value of zero, when the number of the succeeding frames where errors have occurred is larger than or equal to a predetermined number.

According to a third aspect of the invention, there is provided a method for concealing a frame where an error has occurred in a digital audio signal which is subband coded and transform coded in units of an error-correctible frame, the error concealment method comprising the steps of:

(a) receiving frequency coefficients representing the encoded digital audio signal;

(b) detecting whether an error has occurred for each frame with respect to the input frequency coefficients;

(c) decoding the frequency coefficients by respective subbands forming a frequency domain of the whole audio signal with respect to the input frequency coefficients;

(d) storing the frequency coefficients decoded in step (c);

(e) reconstructing the frequency coefficients of a frame where errors have occurred using predetermined weight values and frequency coefficients of frame or multiple of frames adjacent to the frame where the error has occurred in response to the error detection result in step (b);

(f) replacing the frequency coefficients of the frame where the error has occurred by the frequency coefficients reconstructed in step (e); and

(g) converting the frequency coefficients resulting from step (f) into an audio signal of a time domain, in the same sequence as that decoding in step (c).

For a better understanding of the invention, and to show how embodiments of the same may be carried into effect, reference will now be made, by way of example, to the accompanying diagrammatic drawings, in which:

Figure 1 is a schematic block diagram of a conventional digital audio signal encoding/decoding apparatus using a subband coding method;

Figure 2 is a graphical view for explaining a digital audio signal;

Figure 3 is a block diagram showing a conventional error concealment apparatus for a digital audio signal;

Figure 4A-4C are waveform diagrams for explaining error concealment in the figure 3 apparatus;

Figure 5 is a block diagram showing an error concealment apparatus of a digital audio signal according to a preferred embodiment of the present invention;

Figures 6A and 6B are conceptual diagrams for explaining a signal processing of a frequency coefficient reconstruction portion according to the error concealment method provided in embodiments of the present invention;

Figure 7 is a graphical view showing one example of a weight value (α_1) by which a frequency coefficient is multiplied; and

Figures 8A and 8B are conceptual diagrams for explaining a signal processing of a frequency coefficient reconstruction portion according to another error concealment method provided in embodiments of the present invention.

Preferred embodiments of the present invention will be described below in more detail with reference to the accompanying drawings figures 5 through 8B.

The figure 5 apparatus reconstructs an audio signal compressed by the block such as encoder 1 in figure 1 for a digital audio signal. An error detector 10 detects whether an error has occurred for each frame of the input compressed audio signal, and generates an error frame indication signal representing that a frame can not be reconstructed due to an error. A decoder 100 decodes the compressed audio signal in a frequency domain. With respect to the audio signal compressed by encoder 1 of figure 1, the signal input to decoder 100 becomes frequency coefficients of respective subbands. In this case, decoder 100 generates inversely quantized frequency coefficients. The output signal of decoder 100 is supplied to a buffer portion 70. Buffer portion 70 stores the frequency coefficients. A capacity of storing the data in buffer portion 70 is determined by which method of figure 5 apparatus is designed among error concealment methods explained with reference to figures 6A, 6B, 8A and 8B. Frequency coefficient reconstruction portion 60 reads out a signal which is stored in buffer portion 70 according to the error frame indication signal from error detector 10, and reconstructs the frequency coefficients of the frame where an error has occurred, according to a method to be described later. As a result, the frequency coefficients of the error-generated frame are reconstructed by frequency coefficient reconstruction portion 60. The reconstructed frequency coefficients are applied to buffer portion 70. The frequency coefficients of the error-generated frame which is decoded by decoder 100 in buffer portion 70 are replaced by corresponding frequency coefficients reconstructed by frequency coefficient reconstruction portion 60. Buffer portion 70 outputs the stored frequency coefficients in sequence matching a frame sequence to synthesis filter bank 80. Synthesis filter bank 80 multiplies the frequency coefficients of each frame supplied from buffer portion 70 by a windowing function, and transforms the resultant signal into a signal in the time domain. A digital-to-analog converter (DAC) 90 converts the signal applied from synthesis filter bank 80 into an analog signal. Therefore, the output signal from DAC 90 becomes a reproduced audio signal in which the generated error is concealed.

An operation of frequency coefficient reconstruction portion according to the exemplary methods proposed will be described below with reference to figures 6A and 6B. The error concealment method shown in figures 6A and 6B reconstructs the frequency coefficients of each segment in a frame where an error has occurred, using a frequency coefficient of the last segment of a previous frame. With respect to the subband coded audio signal, frequency coefficient reconstruction portion 60 reconstructs the frequency coefficients of the error-generated frame by the respective subbands. Figure 6A shows a case where one frame F_2 is not decoded due to an error. In this case, a value of the frequency coefficient of a first segment S_1 in frame F_2 becomes a value obtained by multiplying the frequency coefficient of the M-th segment S_m being the last segment in frame F_1 by weight value α_1. A coefficient of second segment S_2 is obtained by multiplying a coefficient of first segment S_1 by weight value α_2. The following segments S_3-S_m are processed in the same manner as the above. Thus, the frequency coefficients of the whole segments S_1-S_m belonging to frame F_2 where an error has occurred are reconstructed. Here, weight values ($\alpha_1,\alpha_2,...,\alpha_m$) are positive integers which are generally less than or equal to one and can be determined by a user. For example, if $\alpha_1=\alpha_2,...,\alpha_m=\alpha<1.0$, the frequency coefficients of respective segments S_1-S_m within frame F_2 are obtained by the following expressions.

$$\text{Coefficient } (S_1, F_2) \leftarrow \alpha x(S_m, F_1)$$

$$\text{Coefficient } (S_2, F_2) \leftarrow \alpha^2 x(S_m, F_1)$$

$$\text{Coefficient } (S_m, F_2) \leftarrow \alpha^m x(S_m, F_1)$$

Here, coefficient (S_j, F_i) represents a frequency coefficient belonging to the j-th segment of the i-th frame. At this time, since weight value α is smaller than one, the later the segment is located in one frame, the more sharply the frequency coefficient value is lowered. Such an example is shown in figure 7.

As shown in figure 6B, when succeeding errors occur in several contiguous frames EF_1, EF_2,...,EF_n, the frequency coefficient of the last segment in frame F_1 where an error does not occur, is used to reconstruct the frequency coefficients

of all frames EF_1, EF_2,...,EF_n which are located succeedingly. To reconstruct the frequency coefficients of frames EF_1, EF_2,...,EF_n, a method similar to that explained with reference to figure 6A is applied. As a result, the frequency coefficient value of the m-th segment S_m in the last frame EF_n becomes a value obtained by multiplying the previous weight values in all the error-generated frames. It is preferable in this case that the different weight values can be used in the respective error-generated frames EF_1, EF_2,...EF_n. For example, the following expressions can be given.

$$EF_1 \leftarrow \alpha_1=0.9,\ \alpha_2=....\alpha_m=1$$

$$EF_2 \leftarrow \alpha_1=0.8,\ \alpha_2=....\alpha_m=1$$

$$EF_3 \leftarrow \alpha_1=0.6,\ \alpha_2=....\alpha_m=1$$

$$EF_{(n-1)} \leftarrow \alpha_1=0.1,\ \alpha_2=....\alpha_m=1$$

$$EF_n \leftarrow \alpha_1=\alpha_2=....\alpha_m=0$$

When the weight values are assigned in this way, the frequency coefficient of first segment S_1 in first error-generated frame EF_1 shown in figure 6B is obtained by multiplying the coefficient value of m-th segment S_m in previous frame F_1 by weight value α_1(=0.9). Likewise, the frequency coefficient values of second segment S_2 in first error-generated frame EF_1 is obtained by multiplying the first coefficient values by weight value α_2. Thus, up to the (n-1)-th error-generated frame EF_1-$EF_{(n-1)}$, a reproduced signal is made using a reconstructed frequency coefficient of the previous frame. However, since the weight values of the n-th error-generated frame are all zeros, this interval becomes an audio erasure state. That is, if the weight value is properly adjusted in this manner, an audio muting operation can be performed from any frame.

The above-described method reconstructs the error using the last segment in the previous frame prior to error occurrence, for more convenient explanation. It is however possible to use a coefficient of a different segment which is located near the last segment of the previous frame or future frame.

Figures 8A and 8B are views for explaining a further error concealment method modifying the error concealment method explained with reference to figures 6A and 6B. The error concealment method proposed in connection with Figures 8A and 8B calculates the frequency coefficients of the frame where the error has occurred, through an interpolation operation using a frequency coefficient of the previous frame with respect to the error-generated frame and the frequency coefficient of the following frame with respect to the error-generated frame. The method for calculating the frequency coefficient values of error-generated frame F_2 will be described below. In case of figure 8A, the frequency of the first segment S_1 in frame F_2 is obtained by adding a value of a coefficient value of m-th segment S_m in first frame F_1 multiplied by weight value β_1 to a value of a coefficient value of first segment S_1 in third frame F_3 multiplied by weight value (1-β_1). This can be represented as follows, in the general form with respect to all segments belonging to frame F_3.

$$\text{Coefficient}(S_1, F_2) \leftarrow \beta_1 \times \text{Coefficient}(S_m, F_1) + (1-\beta_1) \times \text{Coefficient}(S_1, F_3)$$

Figure 8B shows an example where the figure 8A method is adapted in the case where the errors have occurred in the several contiguous frames. Since implementation of the figure 8B method will be apparent to those having skill in the art having read the foregoing description and studied figure 8B, the detailed description will be omitted. The weight values α_1 and β_1 referred to in connection with figures 6A, 6B, 8A and 8B can be obtained by a calculation method and can be used in the form of a look-up table.

As described above, the error concealment method and apparatus according to embodiments of the present invention reconstructs the frequency coefficients of the error-generated frame using the frequency coefficient of the contiguous frame, thereby minimizing an influence on the succeeding frames due to the error-generated frame.

While only certain embodiments of the invention have been specifically described herein, it will be apparent that numerous modifications may be made thereto without departing from the scope of the invention.

The reader's attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

Each feature disclosed in this specification (including any accompanying claims, abstract and drawings), may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Claims

1. An apparatus for concealing a frame or multiple of frames where errors have occurred in a digital audio signal which are subband coded and transform coded in units of an error-correctible frame, said error concealment apparatus comprising:

   error detection means (10) for receiving frequency coefficients representing the encoded digital audio signal and detecting whether an error has occurred for each frame;

   decoding means (100) for decoding the frequency coefficients by respective subbands forming a frequency domain of the whole audio signal with respect to the input frequency coefficients;

   buffer means (70) for storing the frequency coefficients decoded by said decoding means (100);

   frequency coefficient reconstruction means (60) for reconstructing the frequency coefficients of a frame or multiple of frames where errors have occurred using predetermined weight values and frequency coefficients of subband(s) adjacent to the error frame(s) among the frequency coefficients belonging to a frame which is stored in said buffer means and is adjacent to the error frame(s), updating the frequency coefficients of the error frame(s) and storing the frequency coefficients in said buffer means (70), in response to the error detection result from error detection means (10); and

   a synthesis filter bank (80) for receiving the frequency coefficients stored in said buffer means (70) and converting the frequency coefficients into an audio signal of a time domain, in the same sequence as a decoding sequence.

2. An apparatus according to claim 1, wherein said frequency coefficient reconstructions means (60) uses frequency coefficients of subbands which exist in the very previous frame of the error-generated frame(s) and is adjacent to the error-generated frame(s), to reconstruct the frequency coefficients of subbands of the error-generated frame(s).

3. An apparatus according to claim 2, wherein said frequency coefficients to be used for reconstruction belong to the last segment of the frame which is immediately preceding the error-generated frame(s).

4. An apparatus according to claim 2 or 3, wherein said frequency coefficient reconstruction means (60) calculates frequency coefficients corresponding to subbands of the error-generated frame(s), by multiplying the frequency coefficient adjacent to the error-generated frame(s) which belongs to the very previous frame for each subband, by a predetermined weight value.

5. An apparatus according to claim 4, wherein said predetermined weight values are less than or equal to one.

6. An apparatus according to claim 1, wherein said frequency coefficient reconstruction means uses frequency coefficients which exist in the very previous frame and the very succeeding frame of the error-generated frame(s) and is adjacent to the error-generated frame(s), to reconstruct the frequency coefficients for subband(s) of the error-generated frame(s).

7. An apparatus according to claim 6, wherein said frequency coefficients to be used for reconstruction respectively belong to the last segment of the frame which is immediately preceding the error-generated frame(s) and the first segment of the frame immediately succeeding the error-generated frame(s).

8. An apparatus according to claim 6 or 7, wherein said frequency coefficient reconstruction means (60) calculates frequency coefficients corresponding to subbands of the error-generated frame(s), by multiplying the frequency coefficient adjacent to the error-generated frame(s) which belongs to the very previous frame for each subband, by a first weight value, multiplying the frequency coefficient adjacent to the error-generated frame(s) which belongs to the very succeeding frame for each subband, by a second weight value, and adding the two multiplication results.

9. An apparatus according to claim 8, wherein said first and second weight values are less than or equal to one.

10. A method for concealing a frame or multiple of frames where errors have occurred in a digital audio signal which is subband coded and transform coded in units of an error-correctible frame, said error concealment method comprising the steps of:

(a) receiving frequency coefficients representing the encoded digital audio signal;

(b) detecting whether an error has occurred for each frame with respect to the input frequency coefficients;

(c) decoding the frequency coefficients by respective subbands forming a frequency domain of the whole audio signal with respect to the input frequency coefficients;

(d) storing the frequency coefficients decoded in step (c);

(e) reconstructing the frequency coefficients of a frame or multiple of frames where errors have occurred using predetermined weight values and frequency coefficients of subbands adjacent to the error frame(s) among the frequency coefficients belonging to a frame adjacent to the error frame(s), in response to the error detection result in step (b);

(f) updating the frequency coefficients of the error frame(s) stored in the step (d) with the frequency coefficients reconstructed in step (e); and

(g) converting the frequency coefficients resulting from step (f) into an audio signal of a time domain, in the same sequence as that decoding in step (c).

11. A method according to claim 10, wherein said step (e) uses frequency coefficients subbands which exist in the very previous frame of the error-generated frame(s) and is adjacent to the error-generated frame(s), to reconstruct the frequency coefficients of subbands of the error-generated frame(s).

12. A method according to claim 11, wherein said frequency coefficients belong to the last segment of frame which is immediately preceding the error-generated frame(s).

13. A method according to claim 11 or 12, wherein said step (e) calculates frequency coefficients corresponding to subbands of the error-generated frame(s), by multiplying the frequency coefficient adjacent to the error-generated frame(s) which belongs to the very previous frame for each subband, by a predetermined weight value.

14. A method according to claim 13, wherein said predetermined weight values are less than or equal to one.

15. A method according to claim 10, wherein said step (e) uses frequency coefficients for subband(s) which exist in the very previous frame and the very succeeding frame of the error-generated frame(s) and is adjacent to the error-generated frame(s), to reconstruct the frequency coefficients for each subband of the error-generated frame(s).

16. A method according to claim 15, wherein said frequency coefficients respectively belong to the last segment of the frame which is immediately preceding the error-generated frame(s) and the first segment of the frame succeeding the error-generated frame(s).

17. A method according to claim 15, wherein said step (e) calculates frequency coefficients corresponding to subbands of the error-generated frame(s), by multiplying the frequency coefficient adjacent to the error-generated frame(s) which belongs to the very previous frame for each subband, by a first weight value, multiplying the frequency coefficient adjacent to the error-generated frame(s) which belongs to the very succeeding frame for each subband, by a second weight value, and adding the two multiplication results.

18. A method according to claim 17, wherein said first and second weight values are less than or equal to one.

19. A method according to claim 10, wherein said step (e) replaces said predetermined weight values for the audio muting by a value of zero, when the number of the succeeding frames where errors have occurred is larger than or equal to a predetermined number.

FIG. 1 (PRIOR ART)

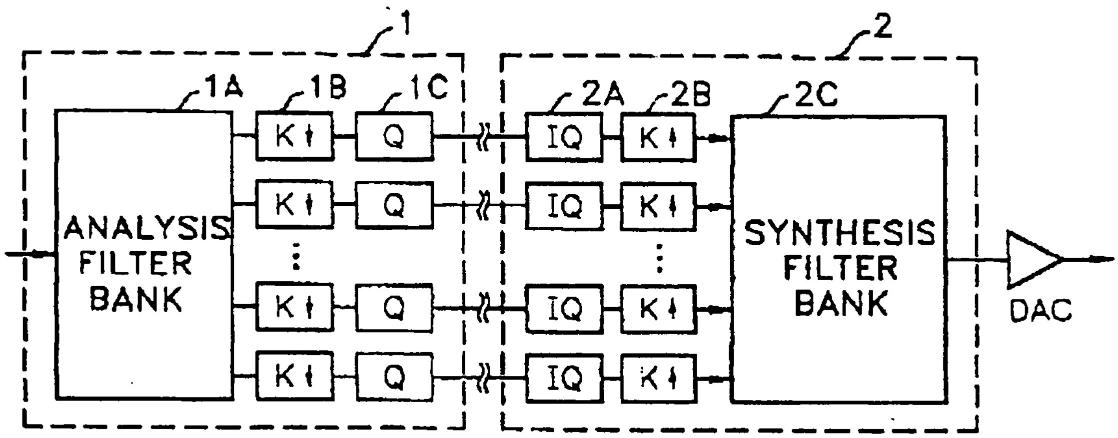


FIG. 2 (PRIOR ART)

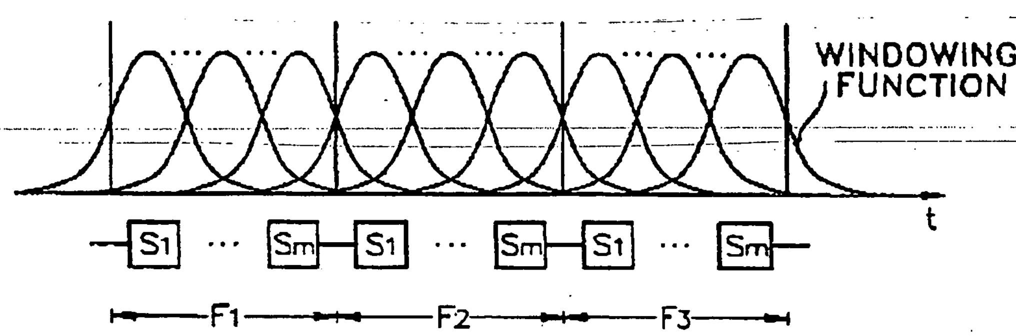


FIG. 3 (PRIOR ART)

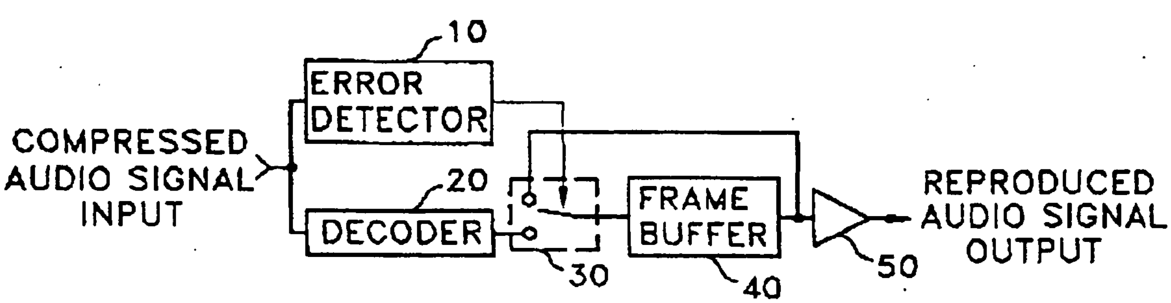


FIG. 4A (PRIOR ART)

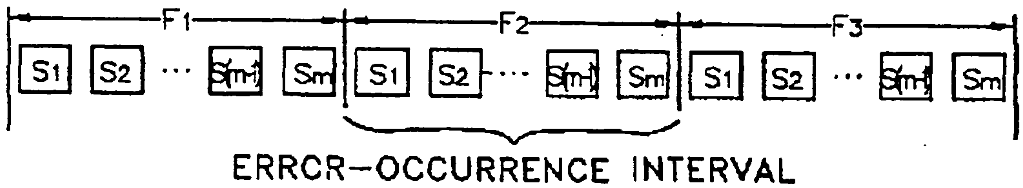


FIG. 4B (PRIOR ART)

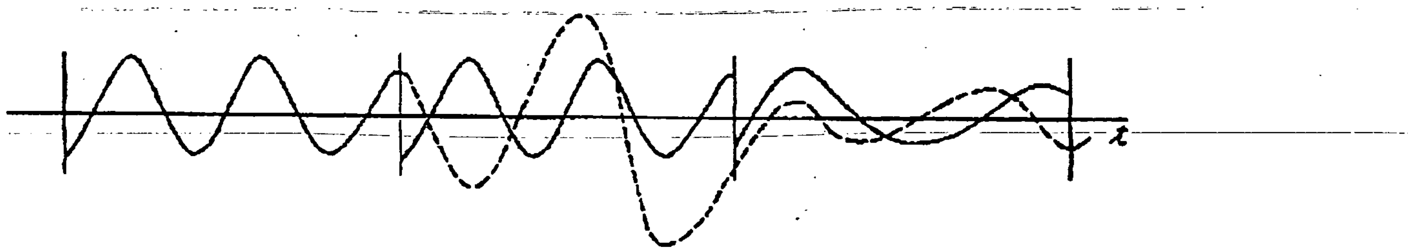


FIG. 4C (PRIOR ART)

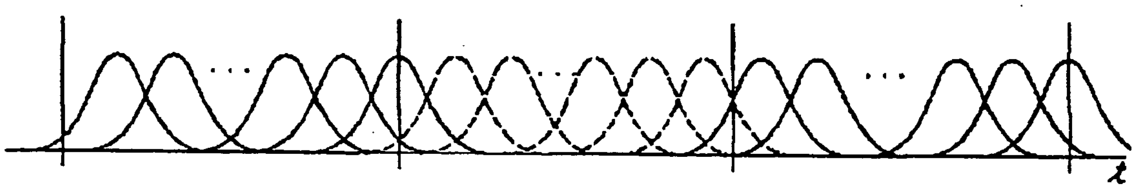


FIG. 5

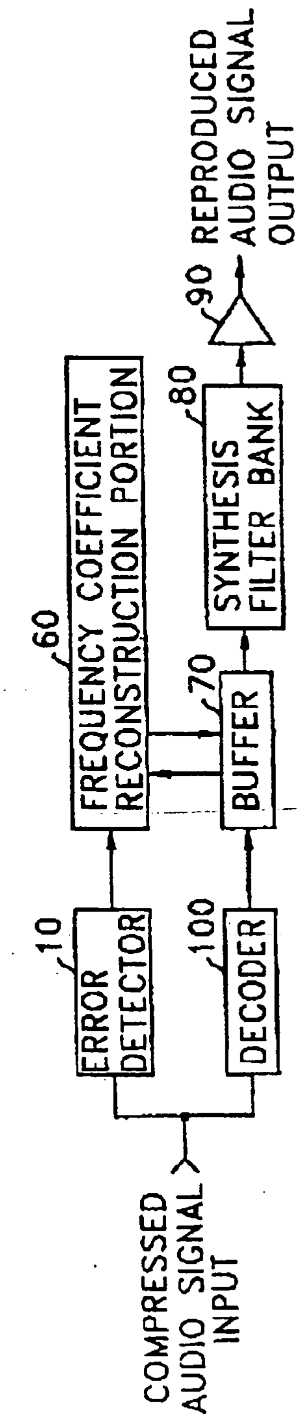

COMPRESSED AUDIO SIGNAL INPUT
ERROR DETECTOR
10
DECODER
100
FREQUENCY COEFFICIENT RECONSTRUCTION PORTION
60
BUFFER
70
SYNTHESIS FILTER BANK
80
90
REPRODUCED AUDIO SIGNAL OUTPUT

FIG. 6 A

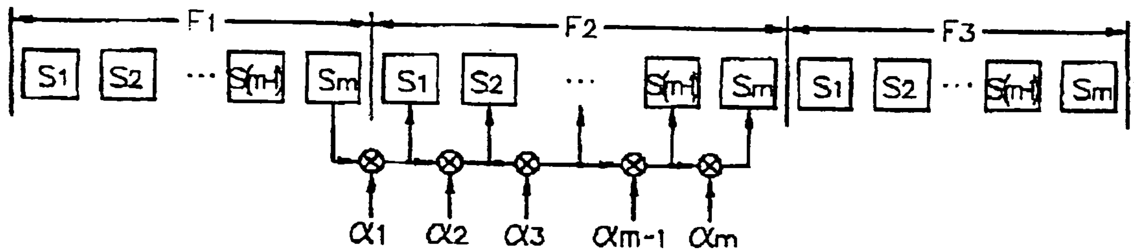


FIG. 6 B

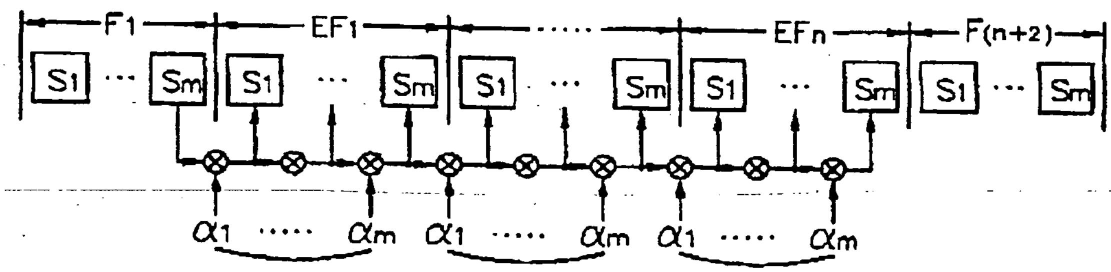


FIG. 7

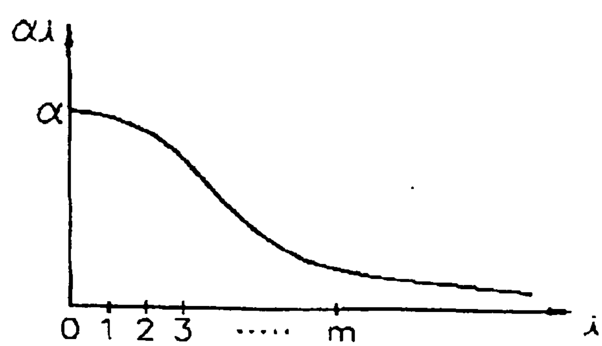


FIG.8A

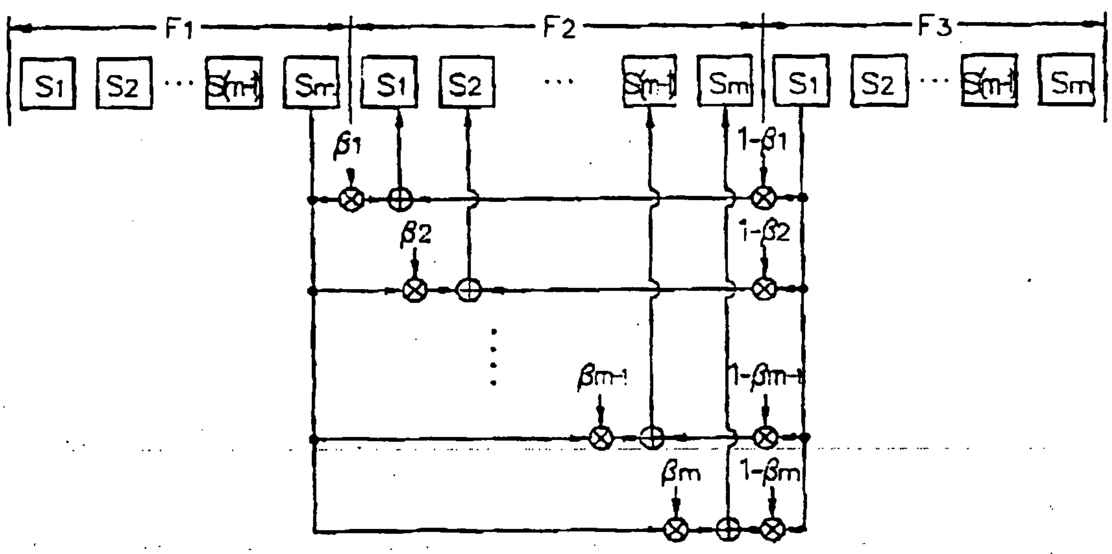
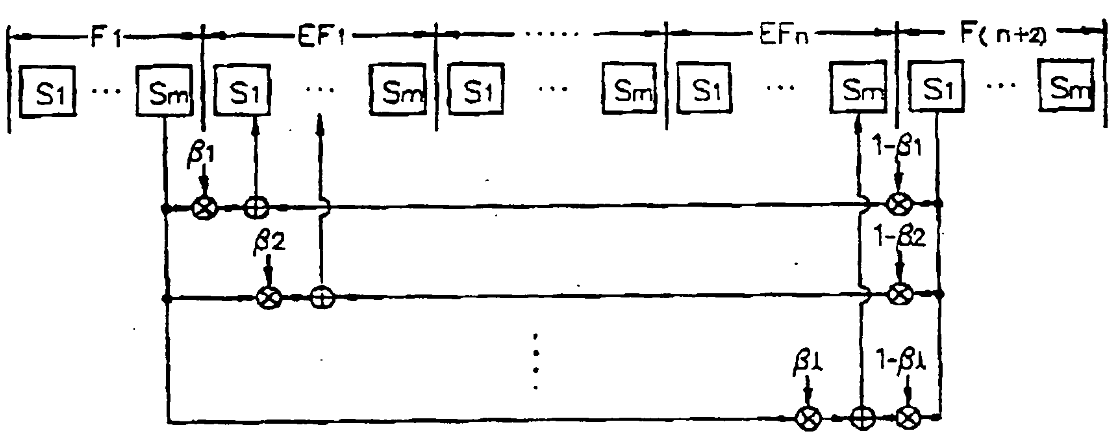

F1
F2
F3
S1
S2
S(m-1)
Sm
β1
β2
βm-1
βm
1-β1
1-β2
1-βm-1
1-βm

FIG.8B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EF1
EFn
F(n+2)
S1
Sm
β1
β2
βl
1-β1
1-β2
1-βl

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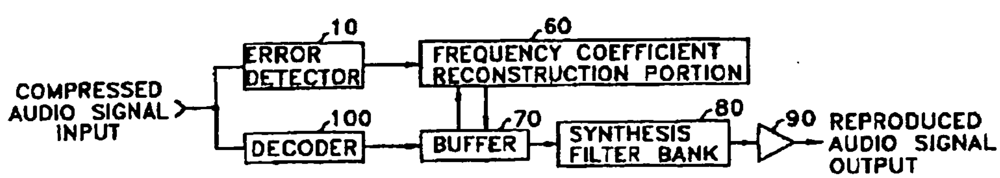
FIG. 5



EP 0 718 982 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 30 9269

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	US 5 148 487 A (NAGAI ET AL) 15 September 1992 (1992-09-15)	1,2,4-6, 8-11, 13-15, 17,18	H04B1/66 H04L1/00 G11B20/18 G10L19/00
Y	* abstract; figure 1 * * column 2, line 32 - column 4, line 13 *	19	
Y	PLENGE G ET AL: "Combined channel coding and concealment" IEE COLLOQUIUM ON 'TERRESTRIAL DAB - WHERE IS IT GOING?' (DIGEST NO.042), LONDON, UK, 17 FEB. 1993, pages 3/1-8, XP002136083 1993, London, UK, IEE, UK	19	
A	* page 1, paragraphs 2,3 * * page 2, last paragraph * * page 3, paragraph 4 * * page 5, paragraph 1 *	1,2,6, 10,11,15	
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	19 April 2000	Quélavoine, R

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EUROPEAN SEARCH REPORT

Application Number
EP 95 30 9269

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 95 30 9269

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CONCISE EXPLANATION FOR DE 197 35 675

DE 197 35 675 discloses a method for concealing errors in an audio data stream. The spectral energy of a subgroup of intact audio data is calculated. After producing a pattern for substitute data using the spectral energy calculated for the subgroup of intact audio data, substitute data for erroneous or missing audio data corresponding to the subgroup are generated according to the pattern.